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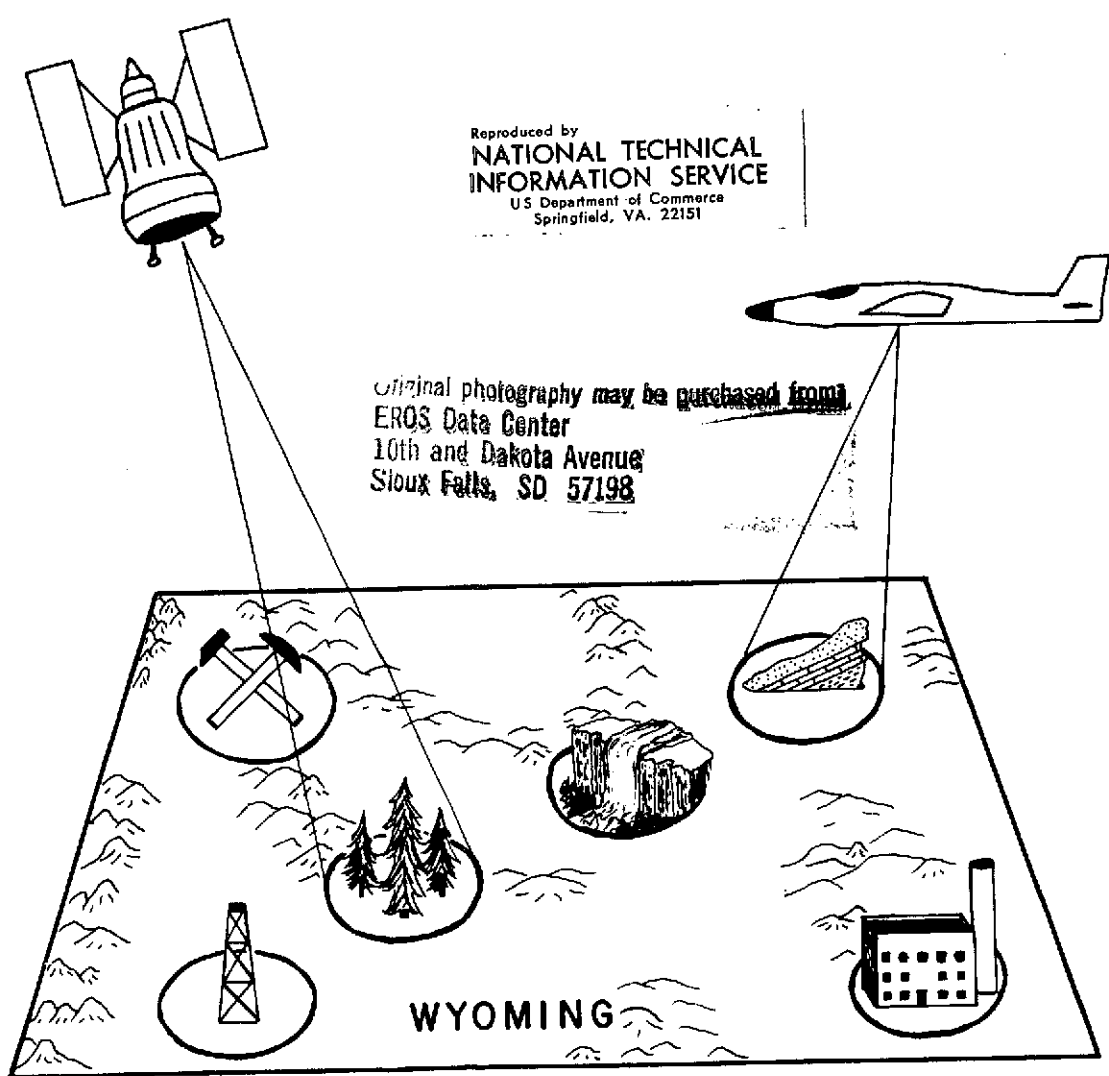
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AND SCOTT B. SMITHSON

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USING THE EARTH RESOURCES TECHNOLOGY
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16. Abstract Reconnaissance geologic mapping can be done with 60-70 percent accuracy in the Dry Valleys of Antarctica using ERTS imagery. Bedrock geology can be mapped much better than unconsolidated deposits of quaternary age. Mapping of bedrock geology is facilitated by lack of vegetation whereas mapping of Quaternary deposits is hindered by lack of vegetation. Antarctic images show remarkable clarity and under certain conditions (moderate relief, selection of the optimum band for specific rock types [band 7 for granite-basalt contacts], stereo-viewing [good side-lap in high latitudes]) irregular contacts can be mapped in local areas that are amazingly like those mapped at a scale of 1:25,000, but, of course, lack details due to resolution limitations. ERTS images should be a valuable aid to Antarctic geologists who have some limited ground truth and wish to extend boundaries of geologic mapping from known areas.					
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RECONNAISSANCE GEOLOGIC MAPPING IN THE DRY VALLEYS OF ANTARCTICA
USING THE EARTH RESOURCES TECHNOLOGY SATELLITE

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SPECIAL REPORT

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RECONNAISSANCE GEOLOGIC MAPPING IN THE DRY VALLEYS OF ANTARCTICA USING THE EARTH RESOURCES TECHNOLOGY SATELLITE

By Robert S. Houston, Frank W. Zochol and Scott B. Smithson

INTRODUCTION

Antarctic terrain offers a unique test of the experimental Earth Resources Technology Satellite (ERTS) of NASA⁽¹⁾ as a tool for reconnaissance geologic mapping. Most of the area is vegetation-free and side-lap of images in the high latitudes is such that stereo-viewing is possible. Tonal differences on images that result from differences in reflectance should be directly related to rock-type so that typical problems encountered in other regions with vegetative cover and rock-soil-vegetation mix reflectance can be eliminated.

(1) The Earth Resources Technology Satellite (ERTS) was launched by the National Aeronautics and Space Administration in July 1972 at an altitude of 560 miles and is an imaging system that orbits in a sun synchronous, near polar orbit and is capable of repetitive coverage of any given area every 18 days. The system is described in detail in symposia published by NASA (Park, 1972; NASA, 1972; Finch, 1973) and summaries are in articles by Loman (1972) and Short, (1973). For geologic mapping the most useful sensor is a multispectral scanner system (MSS) that records radiation in four spectral bands: green (0.5-0.6 micrometers), red (0.6-0.7 micrometers), infrared (0.7-0.8 micrometers), and infrared (0.8-1.0 micrometers). The MSS output is recorded on tape and is reformed as photographic images that cover an area approximately 100 NM on a side. For geologic mapping a 9 1/2 x 9 1/2 inch positive transparency produced as one of the standard data products has proved to be most useful. For most geologic studies the infrared band (0.8-1.1 micrometer) referred to as band 7 has been considered the best for mapping and to be superior to the panchromatic film product most often used in photogeology. The various data products of ERTS are available at the EROS data center of the United States Geological Survey located in Sioux Falls, South Dakota.

The Dry Valleys have been chosen for study because large areas are ice-free, a variety of rock types are present, reconnaissance geologic maps are available for most of the area and detailed geologic maps are available in local areas. An additional advantage of this area is that a topographic map on the scale of 1:100,000 has been prepared by the United States Geological Survey.

The Dry Valleys have the disadvantage of very high relief in areas of steep-walled, U-shaped valleys. This relief results in extreme shadowing because of the relatively low sun-angle (22-25 degrees) and makes correlation of rock types from shadowed or slightly shadowed to sunlit valley sites uncertain.

Figure 1 is an ERTS image of the Dry Valleys, taken in January, 1973, and shows the area mapped for this report and various physiographic features that can be recognized.

METHOD OF STUDY

A photogeologic map of the area between St. Johns Range and Asgard Range (main Dry Valley area) has been prepared. The map was made from positive transparencies by use of a Bausch and Lomb stereo-zoom microscope and a Richards microscopic interpretation table. To facilitate mapping, an enlargement of the area to be mapped was made to the scale of approximately 1:250,000 which is near optimum enlargement from the 70 mm ERTS negative. An advantage of the image obtained from space is illustrated by the fact that the enlarged image was readily fitted to the topographic base with minimal distortion problems. Images of this area were available from satellite passes during late November to early February, but those showing greatest detail and least snow cover were from passes of January 13th and 16th. ERTS band 7 shows the most contrast between the various lithologic units and was therefore chosen for this study.

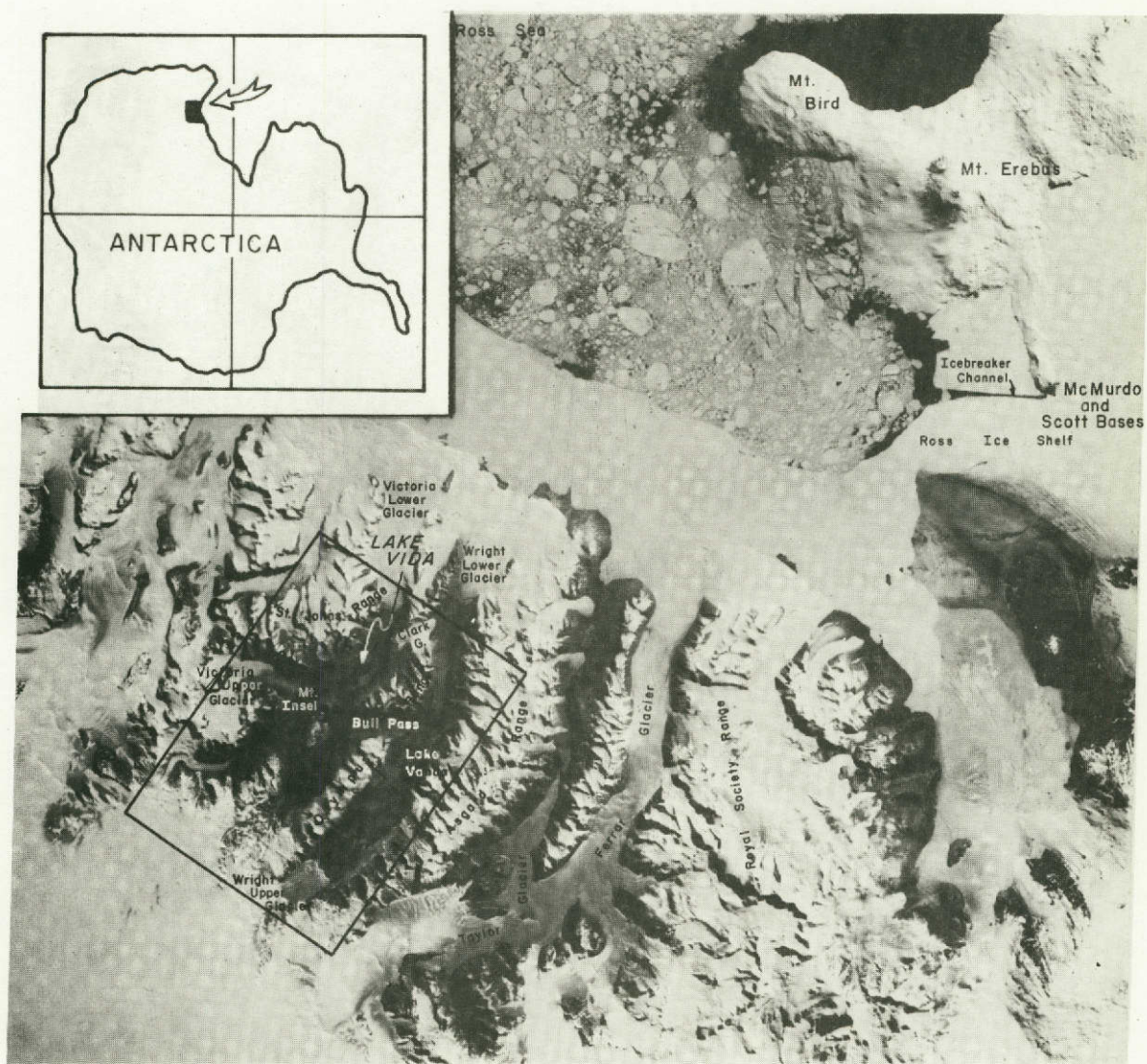


Figure 1 - ERTS band 7 image of the McMurdo-Dry Valley area, Antarctica showing major physiographic features and outline of area of geologic map.

Color-additive viewing techniques (Short and MacLeod, 1972) were employed and some enhancement of rock units was possible (Houston, 1973), but these techniques were more successful in determining the distribution of glaciers and in bringing out ice structure than in geologic mapping.

Maps were also prepared by use of a Joyce Loeb1 isodensitracer (Rackham, 1965) to illustrate the detail that can be obtained from ERTS images by this method and to compare the less-biased "computer" generated map with the photo-geologic map.

PRE-QUATERNARY GEOLOGY WITH A DISCUSSION OF REFLECTANCE OF ROCK UNITS AS RECORDED ON ERTS BAND 7

The Dry Valleys are underlain by rocks that can be divided into three major groups:

1. Basement rocks that include metasedimentary rocks, gneiss, schist and associated syntectonic and post-tectonic felsic intrusions. The metasedimentary rocks are probably Cambrian in age but may include some rocks of Late Precambrian age (Warren, 1969). The metasedimentary and metamorphic rocks are meta-limestones, marbles, biotite and hornblende gneisses, calc-silicate granofels, and diopsidic gneisses and schists. These rocks have been assigned to the Asgard Formation of the Koettlitz Group of the Ross Supergroup by Grindley and Warren (1964). With the exception of the marbles and meta-limestones that show a light tone or high reflectance on ERTS band 7 these units show intermediate to dark tones because they have a higher proportion of mafic minerals (dark colored minerals usually richer in iron).

Syntectonic (originate during orogeny) felsic intrusives include gneissic bodies that commonly grade into metamorphic rocks, and these rocks usually show a great variety of textures and structures as well as variations in composition. Such units may well include rocks that are pre-orogenic (Olympus Granite-Gneiss of Gunn and Warren, 1962) and post-orogenic (Larsen Granodiorite of Gunn and Warren, 1962) or may simply be various facies of reconstituted metasedimentary rock (Smithson and others, 1971). The more homogeneous facies (usually more felsic) of such units may show a higher reflectance on ERTS band 7 than associated metamorphic rocks, but their complex compositional variation suggest that they will show a wide range in reflectance and thus be difficult to distinguish from metasedimentary and metamorphic rocks.

All students of the Dry Valley geology agree that the Irizar Granite is post-tectonic (originated after orogeny). Such granites tend to be clearly cross-cutting with respect to other rocks and more felsic (less iron, more silica) in composition than most associated rocks. These characteristics suggest a uniform light tone or high reflectance for this granite and related rocks on ERTS band 7.

2. Flat-lying sedimentary rocks that overly the basement complex unconformably are referred to as the Beacon Sandstone. At the type section (Hamilton and Hayes, 1963) these sedimentary rocks are approximately 1200 meters thick and consist mostly of sandstone. A basal conglomerate is present in some areas and the upper part of the sequence contains carbonaceous shale and sandstone; locally siltstones, shale, and pebble conglomerate is present. These sedimentary rocks range from Devonian to Jurassic in age. Relatively pure, high-silica rocks such as the

Beacon Sandstone normally are light-toned, highly reflectant rocks in ERTS band 7.

3. Perhaps the most distinctive rocks and certainly the rocks that should be most readily identified on ERTS band 7 are the great diabase sills referred to as the Ferrar Dolerites that intrude rocks of the basement complex and the Beacon Sandstone. These sills may reach a thickness of 450 meters. Three of these thick sills are present in the map area along with a number of related dikes and smaller sills. The lowermost thick sill intrudes the basement complex, the middle sill follows the unconformity (Kukri Peneplain of Gunn and Warren, 1962) between the basement complex and the Beacon Sandstone and the upper sill is within the Beacon Sandstone. These sills are considered Late Triassic to Early Late Jurassic in age (Warren, 1969).

Mafic igneous rocks (rich in ferrous iron) normally show a strong absorption or decrease in reflectance in the near infrared (ERTS, band 7), (Rowan, 1972; Vincent, 1972) which results in very dark tones on the ERTS band 7 image. Such units normally contrast strongly in reflectance with felsic rocks and are thus readily distinguished from granite and sandstone.

The Dry Valley basement complex is cut by hundreds of dikes that range in composition from basaltic to granitic. Most of these dikes are too small to be resolved on ERTS images, but in areas where they are especially abundant faint lines can be noted on the image that trend in the direction of strike of the dikes and probably represent areas where several parallel dikes are close enough together to be resolved as a unit.

EVALUATION OF THE ERTS GEOLOGIC MAP (PRE-QUATERNARY GEOLOGY)

Figures 2, 3, and 4 illustrate the enlarged portion of the ERTS, band 7, image used for compilation of geology (Fig. 2); the ERTS photogeologic map (Fig. 3); and a geologic map of the area compiled from the literature (Fig. 4). Visual comparison of Figures 3 and 4 show that the interpretation using the ERTS image is a useful reconnaissance geologic map. The three major units, basement complex, Beacon Sandstone, and Ferrar Dolerite have been mapped with about 60-70% accuracy and the writers believe that these major subdivisions could be made by an experienced photogeologist whether or not he was familiar with the area.

The Beacon Sandstone can be recognized as a sedimentary rock by its bedded nature, and the relatively high reflectance in band 7 would suggest that the unit is a sandstone, limestone, or dolomite. The Ferrar Dolerite would certainly be considered a mafic igneous rock because of its very strong absorption (dark tone) in the infrared. The basement rocks would undoubtedly be more difficult to distinguish, but the areas underlain by Irizar Granite and other light-colored igneous rocks would probably be identified as felsic igneous rocks since these rock types usually show high reflectance (light tone) in band 7. The irregular contacts of the felsic igneous rocks would also suggest rocks of igneous origin. It is probable that an unbiased photogeologist would have made three subdivisions of the basement complex; the units of low reflectance (dark tone) would be interpreted as mafic rocks (probably metamorphic); the units of intermediate reflectance as igneous rocks of intermediate composition; and the units of high reflectance as felsic igneous rocks. There seems to be little question, however, that the marbles that crop out in the Insel area would also have been interpreted as felsic igneous rocks because of a similarity in reflectance for these rocks and the reflectance of the granite. The reflectance similarity illustrates the



Figure 2 - Enlargement of portions of ERTS image (Fig. 1) used to prepare photogeologic map (Fig 3).

LEGEND



Ice and Snow



Unconsolidated or poorly consolidated deposits



Linear features; (faults, fractures, dikes, unknowns)



Mafic igneous rock (Ferrar Dolerite)



Sedimentary rock (Beacon Sandstone)



Felsic igneous rock



Igneous rocks or gneiss; felsic to intermediate composition



Marble and metalimestone



Metasedimentary rock, gneiss and schist

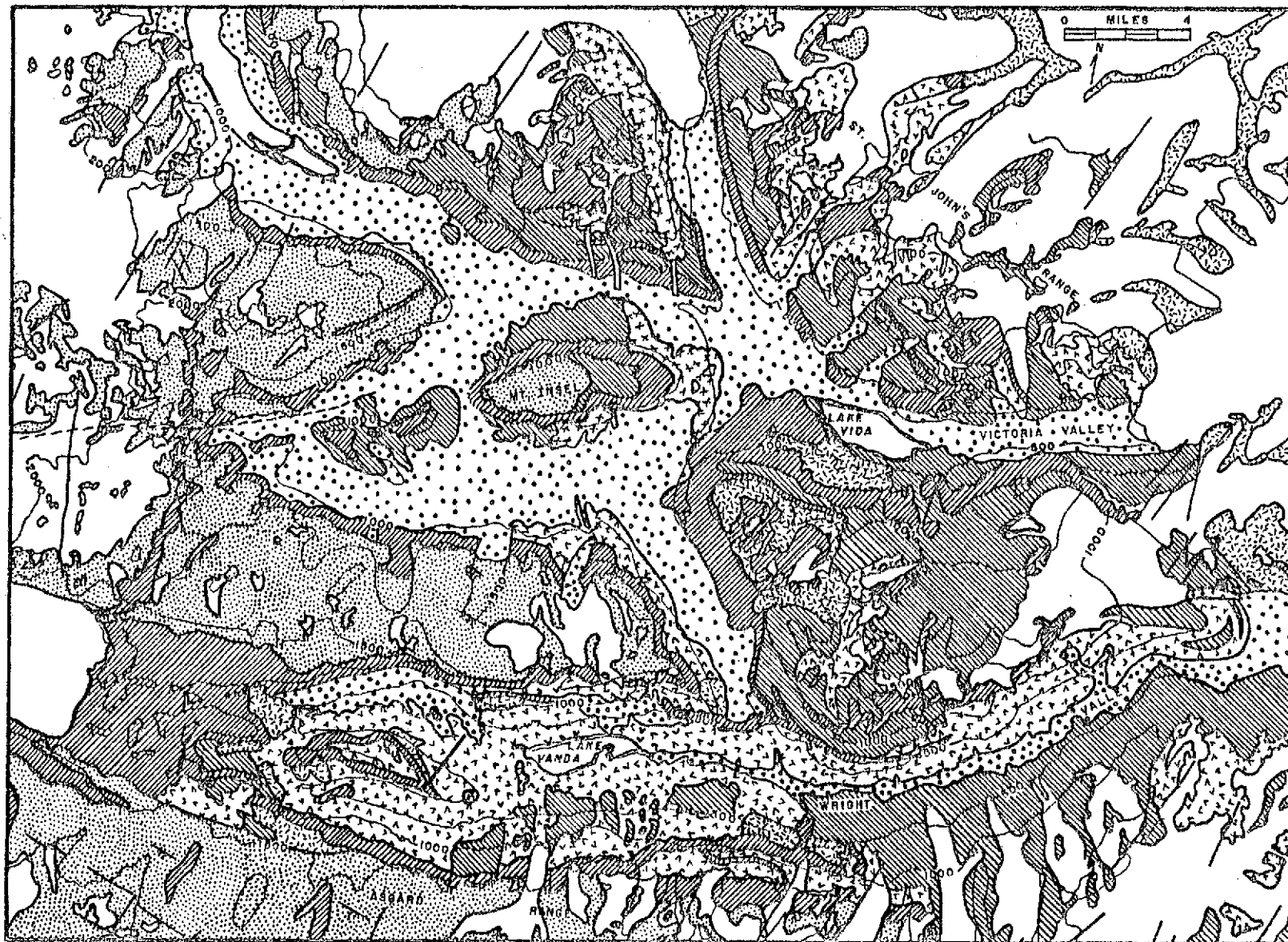


Figure 3. Photogeologic map prepared from stereo-pairs and positive transparencies produced by the Earth Resources Technology Satellite of NASA. Map prepared from infrared band 7 images to illustrate a photogeologic map based on limited field information.

LEGEND



Snow and Ice

Glacial deposits, fluvial deposits, and
deposits that result from mass wasting
(Quaternary)Ferrar Dolerite (Late Triassic to Early
Late Jurassic)

Beacon Sandstone (Devonian to Jurassic)



Dike Swarms

Irizar Granite and related felsic intrusives;
post-tectonic (Late Cambrian to Ordovician)Larsen Granodiorite and Augen gneiss;
syntectonic intrusives and gneiss (Late
Cambrian to Ordovician (?))Metasedimentary Rocks, gneisses, and schist,
undivided. Asgard Formation (Late Pre-
cambrian (?) to Late Cambrian)

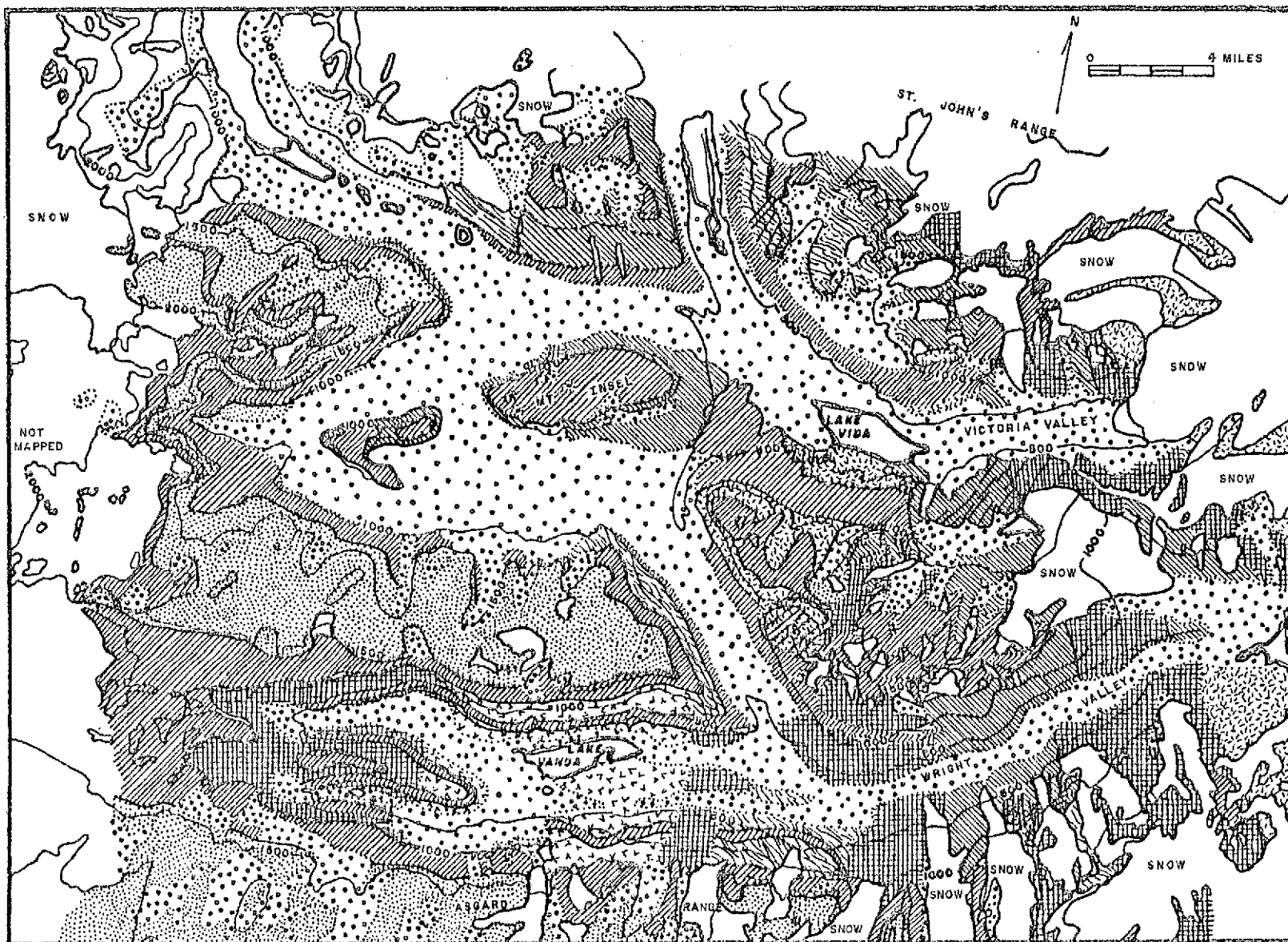


Figure 4. Geologic map of the area between the St. John's Range and Asgard Range, Dry Valley, Antarctica. Generalized from Gunn and Warren (1962), McKelvey and Webb (1962), Allen and Gibson (1962), Fikkan (1968), Smithson (1967-70), Murphy (1971), and Lopatin (1970).

necessity for some type of ground truth (field checks or limited mapping) when photogeologic techniques are employed.







Figure 3 is an example of the type of geologic map that might be prepared from an ERTS image if limited field checks are possible or if geologic maps were available in local areas. For example, distinctions are made between granite and marble which could not be made without ground truth. On the other hand, a number of units are mapped inaccurately because the writers feel that they would have been interpreted in this manner by most photogeologists. As an example, Beacon Sandstone is shown to cap Mt. Insel despite the fact that most geologic maps of this area show the top of the mountain to be underlain by Ferrar Dolerite. We have thus made an attempt to present a type of geologic map (Fig. 3) that could be prepared from ERTS imagery if limited ground truth is available.

EXAMPLE OF OPTIMUM MAPPING RESULTS UNDER IDEAL CONDITIONS

The clarity of the images in Antarctica is remarkable. Although we have not had an opportunity to examine images of northern polar regions we have studied hundreds of images from the Western United States and some from areas outside the United States and very few seem to show the detail that can be seen in those from Antarctica. An illustration of this detail is the contact between the Irizar Granite and Ferrar Dolerite that can be seen south of Lake Vida (Figs. 2 and 3). If we compare the details of this contact as mapped from ERTS, with the same contact mapped on the ground by Fikkan (1968) at the scale of 1:25,000 the correspondence is excellent (Fig. 5). The Ferrar Dolerite sill of this area intrudes the Irizar Granite, probably following a horizontal fracture system in the granite, and the dolerite is both overlain and underlain by granite.







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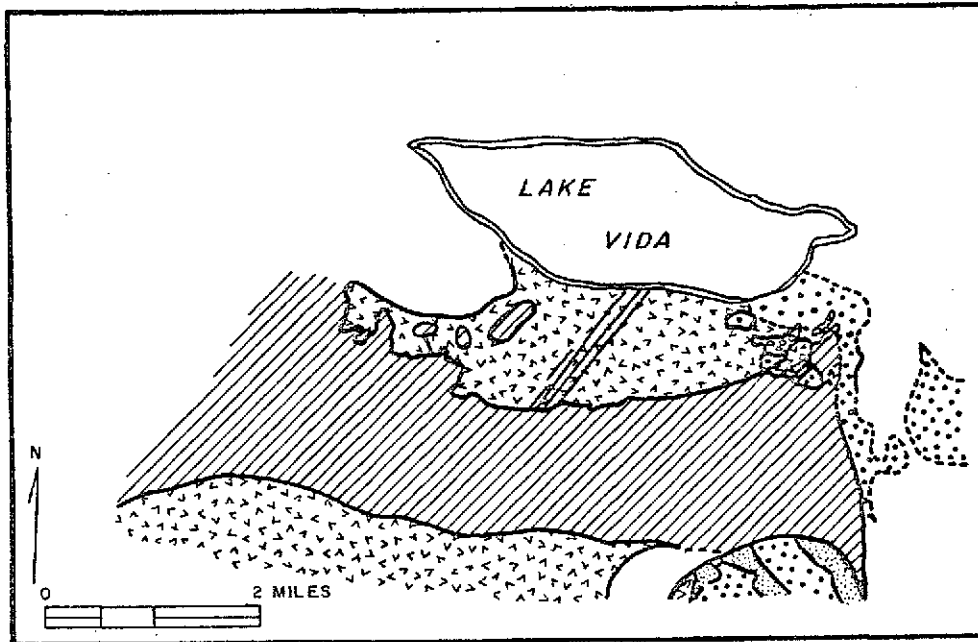
A

-  Ferrar Dolerite
-  Mafic dike
-  Granite and Diabase
-  Irizar Granite
-  Syntectonic felsic bodies
-  Metasedimentary Rocks

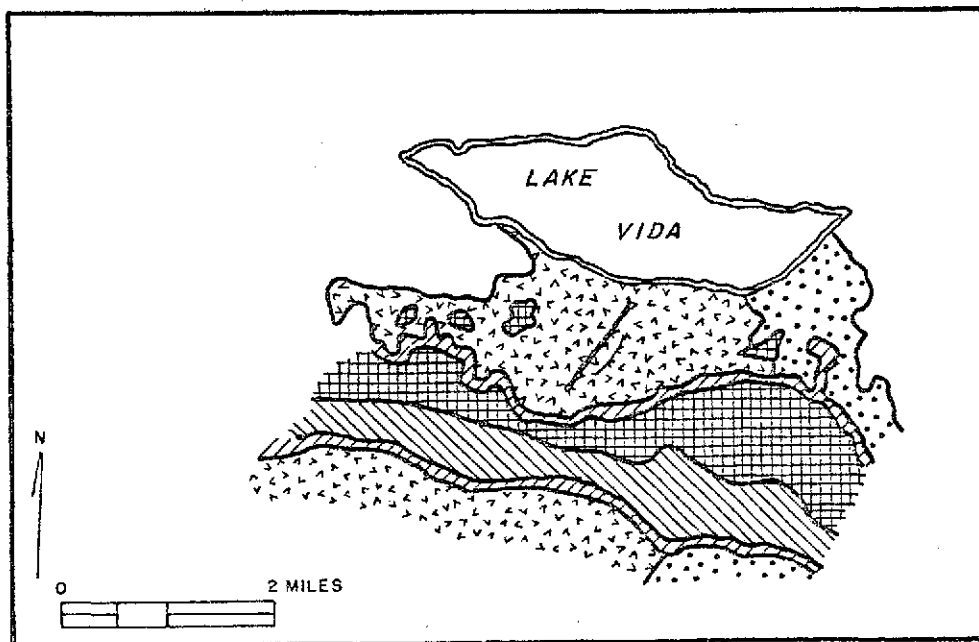
LEGEND

B

-    } Facies of Ferrar Dolerite
-  Dikes
-  Irizar Granite
-  Metasedimentary Rocks



A.



B.

Figure 5. Comparison of geologic map [A] (Fikkan, 1968) originally made at $1/25,000$ scale with photogeologic map [B] prepared from a portion of an ERTS image.

The contact at the south border of Lake Vida is developed by erosion of the base of the sill exposing the underlying Irizar Granite. Several patches of basal dolerite lying on the Irizar Granite that are less than 50 meters in width can be recognized, and several dikes that cut the granite that are less than 14 meters in width can be recognized as a linear feature although they cannot be resolved individually.

Another interesting aspect of this part of the ERTS image is that the basal part of the Ferrar Dolerite sill is darker than the upper part, in fact, the sill can be divided into 4 zones using the ERTS image; a thin very dark zone at the base, a thick zone of slightly lighter tone above this, a thick zone of gray tone above this, and a thin dark zone near the top of the sill (Figs. 2 and 5). This same zonation in the Ferrar Dolerite sill can be seen in a United States Navy oblique photograph taken of this area in 1971 (Fig. 6). The zonation of the sill must be related to texture and mineralogical composition but unfortunately this particular sill has not been subdivided in the field nor has it been sampled adequately so that variation in mineral percentages can be determined. Webb and McKelvey (1959, p. 134-135) state that this sill has been sampled at 200-foot intervals but their petrography is too generalized to determine if the sill is differentiated. Gunn (1962, p. 820-863) described a sill located in the Kukri Hills south of the Lake Vida locality but probably in the same stratigraphic position and probably a part of the same sill discussed here. He (Gunn, 1962, p. 826-836) shows that this sill is differentiated and that the lower two-thirds of the sill is richer in mafic minerals (dark colored pyroxene mostly), and the upper one-third richer in felsic minerals (light-colored feldspar mostly). Perhaps the tonal variations noted in both the ERTS image and the



Figure 6 - United States Navy photograph showing frozen Lake Vida in left background, Irizar granite (light gray) to right of lake, layered sill of Ferrar dolerite to the right of the granite, and Irizar granite in upper right. Note that sill is zoned with a dark layer at base, a dark gray unit above this, a unit of intermediate tone above this, and a dark layer at the top. Compare with Figures 5B and 2.

U.S. Navy photograph do indeed express mineralogical variations similar to those described by Gunn. If so, the very dark zones at base and top may be chilled borders (usually darker in color because of the fine grain of constituents) and the lower dark gray zone may simply be pyroxene-rich as compared with the upper light gray zone.

The excellent relationship between ground truth and photogeologic interpretation in this particular locality may result from several factors. Perhaps the most important is selection of the best photographic band for distinguishing this particular rock. ERTS band 7 (near infrared) has proved to be, if not optimum, at least a very good band for distinguishing granite (or rocks with low ferrous iron that show high reflectance) from basalt (or rocks with high ferrous iron that show strong absorption). Another important factor is that this area is one of relatively low relief and the sun angle and sun location was such that the rocks received even illumination and no shadowing. Finally, it appears that resolution, in general, may be somewhat better in Antarctic perhaps because of less scattering in the clear atmosphere.

QUATERNARY GEOLOGY

Sediments of direct or indirect glacial origin are, by far, the most important deposits of Quaternary age. Calkin (1964) recognizes two major episodes of glaciation in the Dry Valleys which he designates as Insel and Victoria glaciations. The Insel glaciation results from a strong advance of inland ice (ice from the Antarctic continent) that moved eastward into the Dry Valleys. Calkin (1964, p. 27-28) describes Insel drift as very silty, fairly homogeneous, containing clasts that are chiefly mafic igneous rocks from the Ferrar Dolerite, and, as being marked by extensive mantling by solifluction. The Victoria deposits are thought to result from a westward advance of glaciers from the seaward side of the Dry Valleys and Calkin was able to subdivide these younger deposits into

three parts, each related to an advance from the seaward side of the Valley and subsequent retreat. The Victoria drift is described as less silty and somewhat more heterogeneous in lithology of clasts than the Insel Drift. These younger deposits have better developed glacial topography, especially the deposits of the most recent episode of glaciation. Other Quaternary deposits include alluvial sand and gravel, dune sand, unsorted material in debris fans, lake silts, and various deposits of mass wasting such as talus, mudflows, and solifluction sheets.

These Quaternary deposits cover more than one-third of the area mapped as can be seen by inspection of Calkin's (1964) map of the Quaternary deposits of Victoria Valley (Fig. 7). They are, however, very difficult to distinguish from bedrock using ERTS images probably for several reasons: lack of characteristic vegetation that often helps distinguish these types of deposits outside of Antarctica; a dominance of mechanical over chemical weathering that results in less chemical change, therefore less color change between bedrock and clastic deposits derived from it; and also even stereo-viewing fails to reveal the characteristic topography of these rocks from space.

Some of the deposits that result from mass wasting such as debris fans and large masses of talus can be recognized but none of the deposits of drift or even alluvial deposits can be distinguished with certainty. A dark tonal area due south of the Insel Range (compare Figs. 2 and 7) is probably Insel drift. The eastern contact between this Insel drift and a markedly lighter-toned Victoria drift is clearly seen on ERTS images. Probably in this case the Insel drift has a greater proportion of boulders and pebbles of mafic igneous rock so that it is darker in tone than the Victoria drift, but Victoria drift is also present west of the Insel drift and here the two types cannot be distinguished probably because both have a high proportion of mafic rocks in this area.

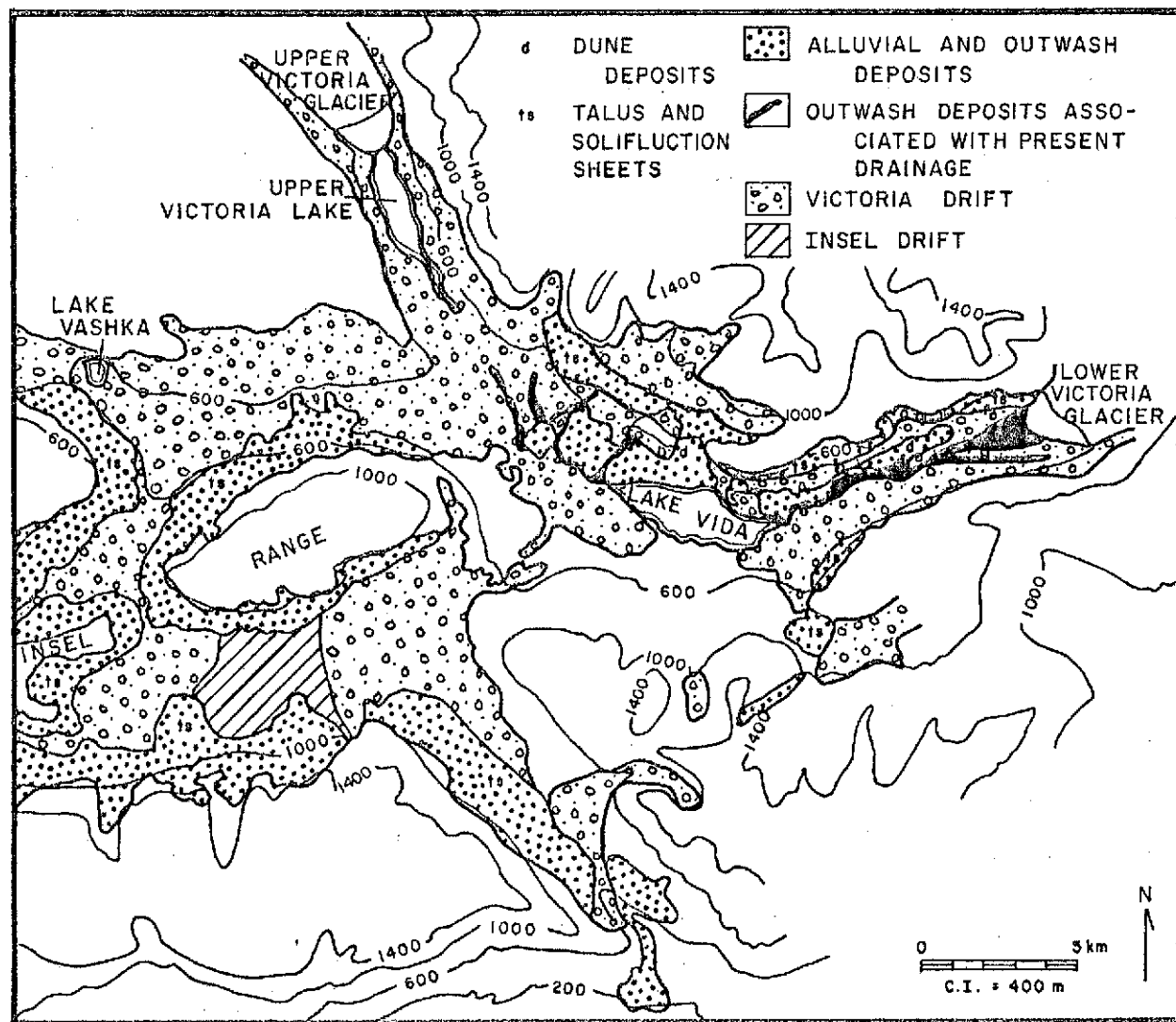


Figure 7. Glacial geology in the Victoria Valley region (generalized from Calkin, 1964).

Sand dunes that are readily recognized on ERTS images in most parts of the world (Houston and Short, 1973; McKee, 1973) are also difficult to distinguish in this area. Several large areas of dune deposits are present north and east of Lake Vida (Fig. 7) and they seem to appear as areas of somewhat lighter tone on the ERTS image, but these areas cannot be recognized as dunes nor can they be separated from other rock types.

It seems clear that the ERTS images could be helpful in tracing contacts between Quaternary units in some cases but these units would have to be identified by use of low level aircraft images or on the ground before any meaningful mapping could be done.

Lack of vegetation in Antarctica has great advantages to the individual interested in mapping bedrock, but appears to be a disadvantage in the mapping of unconsolidated Quaternary deposits that are often characterized by a distinctive vegetation type in other regions. Furthermore, bedrock is itself difficult to distinguish from the Quaternary deposits so that additional mapping errors are likely without ground control. A number of these errors can be noted by comparing figures two and three, where, for example large areas of Quaternary deposits are mapped as intermediate igneous rocks or felsic gneiss in the southwest part of the mapped area.

MAP PREPARED BY USE OF THE ISODENSITRACER

A Joyce Loebel-Tech Ops four-color isodensitracer was used as an aid in constructing "geologic" maps from positive film transparencies. This machine consists of a Joyce-Loebel scanning microdensitometer with a stepping and contouring attachment. The isodensitracer constructs density level contour maps by comparing different gray levels or shades of gray in the transparency with a reference gray

level wedge. The instrument is programmed to produce as many as 64 patterns each representing a different gray level on the transparency. In general, rock types cannot be distinguished by, programming the computer to map a specific gray level corresponding to a given rock type because there is commonly too much overlap in gray level (reflectance) between rock units or between rocks and other substances such as soil and vegetation. Limited success in constructing geologic maps from reflectance data has been achieved by use of several bands combined by use of ratioing techniques or other methods (Lyons, 1968; Smedes and others, 1972; Vincent, 1973), but these methods require major computer facilities and are, as yet, experimental.

Inasmuch as Antarctica is an area where computer mapping is not complicated by vegetation, soil, or the works of man an attempt was made to construct a simple geologic map by density slicing band 7 positive transparencies. In constructing the geologic map an effort was made to distinguish four major rock types; Beacon Sandstone, Ferrar Dolerite, Irizar Granite, and metasedimentary rocks, undivided. Snow-cover was programmed as blank or uncolored. These rock types were programmed by training the small aperture on occurrences of the different rock types identified by field geologists. Figure 8 shows the result of this study and illustrates that even in Antarctica a simple technique of this type is not applicable to geologic mapping because of the wide range of gray levels for these rock types that causes overlapping. The computer did produce a fairly accurate map of snow cover, but the overlap in gray level was such that ablating ice of the Ferrar Glacier was mapped as Irizar Granite.

Figure 9 is a computer map of a part of the area shown in Figures 5a and 5b. This map illustrates the type of detail that can be extracted from the image by use of the isodensitracer, and shows that in small areas it is possible to map lithologic units with reasonable accuracy.



Figure 8. Isodensity contour map of a portion of ERTS-1 image 1174-19433, Dry Valleys, Antarctica.

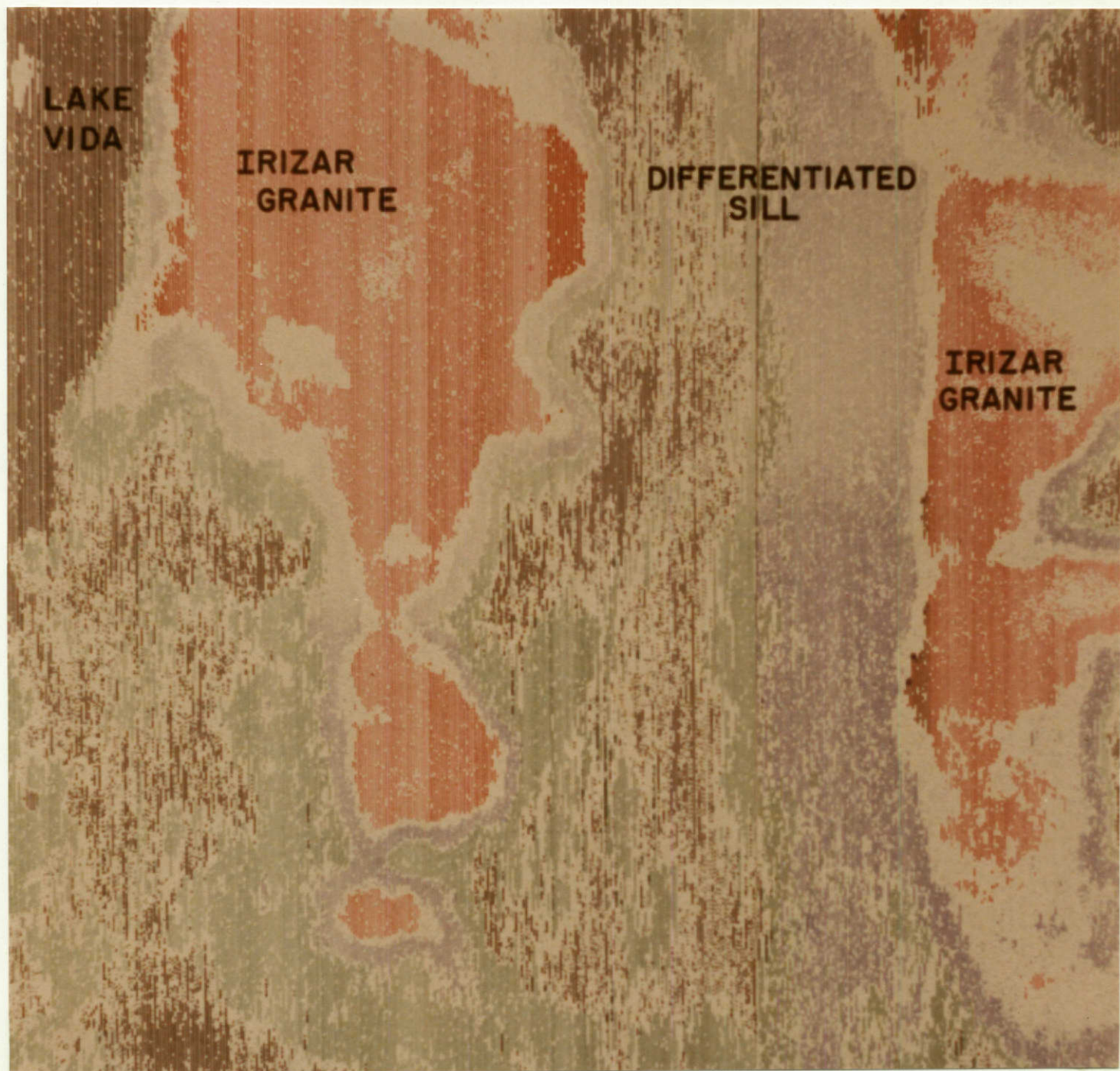


Figure 9. Detailed isodensity contour map of differentiated sill in the Lake Vida region (Compare Fig. 5).

PRESENT AND FUTURE POTENTIAL

The ERTS-1 satellite is experimental and was designed as a tool for multidisciplinary use. For example, one of its great advantages is repetitive coverage of a given area that allows the agricultural scientist to establish his crop calendar (Colwell, 1970) and aids the land planner in determining growth patterns in urban and rural areas. It has been assumed that one good image of an area is all the geologist needs to study rocks since most geologic phenomena seems permanent in the human life span. In many areas such as extremely cold climates like Antarctic or very dry climates such as the Sahara this may be essentially correct, but some rock types may be identified by vegetative cover that changes seasonally and structure is clearly enhanced in some areas by light snow cover (Webber and Martin, 1973). Geologists are also well aware that many geomorphic processes and sedimentation processes as well as volcanism may show changes within a year more extensive than any seen by the land planner. Still the repetitive system is not as useful to geologists interested primarily in mapping as it is to other scientists.

The ideal mapping sensor for the geologist is one that through selection of the proper spectral band or combination of spectral bands allows him to identify specific rock types or to determine the chemical or mineralogical composition of rocks. This is the search for the so-called spectral signature (a unique reflectance for a specific rock type in a given spectral region or a combination of spectral regions) and some limited success has been had in this search using parts of the spectrum not covered by ERTS such as the far infrared (Lyons, 1968) and the ultraviolet (Hemphill, 1968) and by use of narrower bands than those prescribed for ERTS (Rowan, 1972).

It is doubtful that, at present, an ideal space sensor system for geologic mapping could be devised because of the limited success researchers have had in establishing the spectral signatures of rocks, but ERTS-1 is an approach in this direction. The ERTS mechanical scanner system produces a record of the electromagnetic energy received from earth that can be formatted in tapes for computer processing. This allows use of all four bands individually or in combination and the exploitation of minor differences in reflectance between bands that maybe useful in distinguishing rocks. Vincent (1973) has constructed computer derived ratio maps (band 7, divided by band 5) from ERTS tapes that successfully discriminate iron formation in Precambrian rocks of Wyoming and it is obvious from the inspection of ERTS images that red beds can be successfully identified when bands are combined to produce a color infrared composite. This suggests that, in time, remote sensing techniques will be devised that allow automatic mapping of some rock types and that with the right band combinations certain rocks may be distinguished by photogeologists. Nonetheless we remain in a situation where standard photogeologic mapping techniques are still the most useful for geologic studies with ERTS data and rocks must be identified by a combination of texture, structure, association, comparison of image tone with known areas, or from prior knowledge of an area.

In Antarctica geologic studies were quite limited until the beginning of the International Geophysical year in 1957-1958 and the continuation of studies by geologists of many nations since that time, but by 1970 mapping had advanced to the point that Craddock (1970, p. 1) was able to state that "few areas of significant rock exposure remained unvisited by geologists". Nonetheless much of the geologic mapping remains reconnaissance in nature and because of weather conditions and severe problems of access, future work will be both expensive and limited in scope.

The writers are uncertain how much of the Antarctic continent has been covered by ERTS-1 sensors, but if images of most areas show the unusual detail exhibited by those of the Dry Valley area they should be most useful in reconnaissance mapping. Optimum use of images can be made where some ground truth is available (that is, where traverses have been made and rock types identified along them). The images may be best used by geologists who are experienced in a given area to trace contacts with greater accuracy and extend maps beyond control areas. A general survey of Antarctic images may well show some areas that have been overlooked by geologists (Southard and McDonald, 1973) despite the activity since the International Geophysical Year.

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